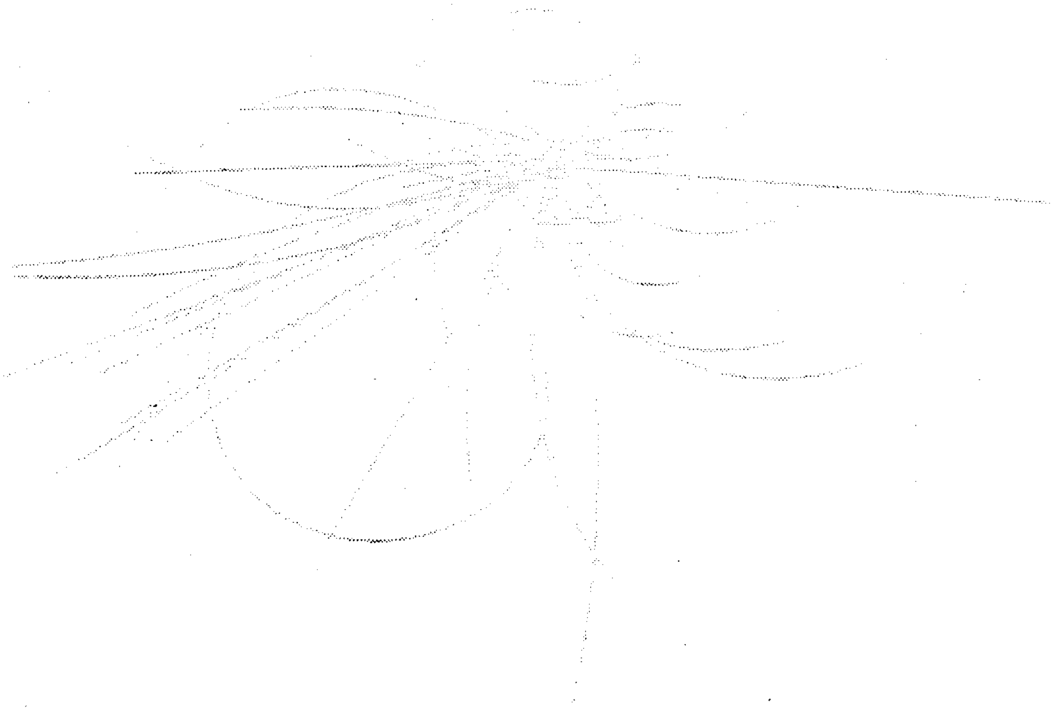
SSCL-Preprint-127
UCLA–PPH0040–2/92

SSCL-Preprint-127
UCLA–PPH0040–2/92

Superconducting Super Collider Laboratory



Tracking with Scintillating Fibers and Visible Light Photon Counters

M. Atac, et al.

June 1992

SSCL-Preprint-127
UCLA-PPH0040-2/92

Tracking with Scintillating Fibers and Visible Light Photon Counters

M. Atac, J. Park, D. Cline and D. Chrisman
University of California at Los Angeles

M. Petroff
Rockwell International Science Center

F. Bird, H. Fenker, K. Morgan and J. Thomas
Superconducting Super Collider Laboratory*
2550 Beckleymeade Ave.
Dallas, TX 75237

B. Baumbaugh, M. Kelly, J. Piekarz and R. Ruchti
University of Notre Dame

B. Abbott, R. Davies, D. Koltick
Purdue University

June 1992

---

* Operated by the Universities Research Association, Inc., for the U.S. Department of Energy under Contract No. DE-AC35-89ER40486.

Introduction

The speed of response and high granularity of scintillating fibers make them an ideal choice for a high-resolution charged particle tracking system, which provides fast first-level triggers and can operate at the highest luminosities the Superconducting Super Collider (SSC) or the Large Hadron Collider (LHC) are capable of producing. A group of institutions, the Fiber Tracking Group (FTG) [1], have been developing scintillating fiber tracking technologies [2].

The response time of a scintillating fiber can be as fast as 5-10 ns depending on the doping dye. A practical diameter of a fiber used in a charged particle applications can range from 250μm to 1 mm. Such granularity provides excellent two track separation and can yield measuring resolution for high momentum tracks limited only by the position accuracy of the fibers.

Until recently, applications of the scintillating fibers to the problem of tracking charged particles has been hampered by the lack of a photon transducer with high quantum efficiency in the wave length region of maximum transmission for polystyrene ~550 nm. This has now changed dramatically with the invention and development of solid state photon counters by Rockwell International Science Center [3]. These devices called Visible Light Photon Counters (VLPC's) have measured quantum efficiencies as high as 85%. The devices are fast, with intrinsic rise times of a few nanoseconds, and can operate at rates as high as 10^7 photons/ sec. Using VLPC's as a transducer, it will be shown in a small scale test, that fiber tracking is a very viable option for charged particle tracking.

Experimental Arrangement

Four scintillating fiber ribbons were stacked and placed in a rectangular black plastic channel. Each ribbon is composed of 8 scintillating fibers which are held together with white reflective acrylic coating. The 4 central fibers on each ribbon are used to make a 16 channel array. The scintillating fibers, 0.83 mm thick, are made of polystyrene doped with 1000 ppm 3HF, and are connected to the same diameter non-scintillating clear fibers using small acrylic blocks. The scintillating fiber ribbons are 4 meters, the clear fibers are 3 meters in length. Fig.1 shows this experimental arrangement. The acrylic blocks are precisely drilled to the fiber diameter and held together precisely using pins and screws. The fibers are glued with epoxy to the acrylic block and their ends are polished to make good optical joints. A thin layer of optical grease is used between the blocks to improve the optical transmission. At the other end of the fiber array the fibers are placed into the same type of acrylic block and glued into place. The fibers are then polished and coupled directly to a mirror which will reflect back light which would otherwise be lost out of the end of the fibers. The fiber geometry is shown in Fig. 2.

The precise fiber geometry was determined by recording many cosmic ray tracks. By triggering on fibers in layers 1 and 4, and searching for the hit fiber or fibers in layers 2 and 3, the geometric alignment between the fibers was determined. This was done for all combinations of the fibers in layers 1 and 4.

The cosmic ray trigger consisted of a plastic scintillator telescope of 0.7 cm by 10 cm size placed above the fiber array. The width of the telescope was chosen to be wider then the four central fibers so that there was no geometric limitation in the trigger. To ensure that the cosmic rays used for the test were minimum ionizing, a 10 cm thick lead brick and a third scintillator were placed below the fiber array. The experiment was performed with and without the brick in place.

A single bias voltage of 6.3 volts was used for the two 8 channel VLPC arrays. The signal from each VLPC element was amplified by a FET input transconductance amplifier (AD3554-AM) which has a rise time of 70 ns. Each amplifier was operated at the same bias voltage, resulting in a gain uniformity of 5% for all 16 channels. This gain uniformity can greatly simplify operation of these devices in large systems.The VLPC's were operating with a gain around $3x10^4$. The operating temperature of the VLPC's was 6.5 K. The amplifiers were readout using Le Croy 1885F FASTBUS ADC's. The ADC's have dual dynamic ranges with two slopes. This wide dynamic range is needed in order to measure charge up to 1000 pC.

Experimental Results

Due to the low cosmic ray event rate, the ADC calibration was achieved by irradiating the fiber array with 1 MeV gamma rays from a ^{60}Co source and triggering on the light from the Compton electron produced inside an individual fiber. The source was held at the end of the 7 meter fiber array. Fig.3 shows the pulse height spectrum obtained. The calibration between the number of photoelectrons and charge in picocoulombs was obtained from this spectra and is plotted in Fig 4. In the fit the first photoelectron peak was not used because the signal threshold imposed excluded the lower tail of this peak. The threshold cut was necessary to reduce the single photoelectron peak that is mainly produced by the thermal electron background in this self triggering calibration mode of operation. The calibration was performed for each and every channel of the second and third fiber ribbon layers.

Fig. 5 shows the corresponding charge in picocoulomb per photoelectron for each fiber channel in these layers. The variations are mainly due to gain variations of the transconductance amplifiers. The average value of 33pC per photoelectron was taken to be the electronic gain for the tests presented below.

The plastic scintillator telescope indicated in Fig.1 was kept at four different positions along the fiber array to trigger on cosmic rays starting from the end of the fibers. Several thousand events were accumulated at each position of the telescope. A large fraction of the tracks did not go through the 4 central fibers of the ribbons due to the fact that the width of the telescope is about twice as wide as the width of the four fibers. Fig.6 shows the photoelectron histogram produced by cosmic rays from the fibers in layer 3 when layers 1 and 2 were triggered at a distance of 6.5 m from the VLPC. As seen in the figure the weighted average number of photoelectrons is 6.2. All events above 0.5 photoelectrons were accepted in the distribution. The histogram distribution seen in Fig. 6 was the same within 0.1 photoelectrons when the telescope above the fiber array was in triple coincidence with the scintillator below the 10 cm thick lead brick. The inefficiency seen in the histogram distribution is mainly due to geometric arrangement of the fiber ribbons as shown in Fig. 2. Some of the cosmic ray tracks miss layer 3 due to the staggering of the layers.

Fig.7 shows the average number of photoelectrons obtained from layers 2 and 3 at four different positions of the scintillator telescope. It also shows one data point when the mirror was removed from the end of the fibers.

The tracking efficiency of the second and third fiber layers, for minimum ionizing tracks, was obtained by triggering on the two middle fibers in layers 1 and 4 while counting the hits in the second and third layers. Fig. 10 shows the efficiency of the second and third layers as a function of trigger threshold in the first and fourth layers. It shows that the efficiency is flat between one and three photoelectron threshold cuts. About 95 % efficiency was obtained by counting the hits in layer 2 and layer 3. About 98.7 % efficiency was found by counting hits in either layer 2 or layer 3. The small inefficiency is mainly due to geometric effects produced by tracks passing through the non-scintillating fiber cladding. This 15 micron thick cladding produces an effective gap in tracking.

Some typical cosmic ray tracks are shown in Fig. 8. The tracks are seen to be very clean without inter-fiber cross-talk. Fig.9 shows some exotic tracks selected by computer. There is evidence for delta ray production, as indicated by the excessive number of photoelectrons either within the hit fiber or an adjacent fiber.

Also, excellent time resolution is obtained. The time response of the VLPC has been tested using a fast transconductance preamplifier [4](The VTX preamplifiers used by CDF collaboration). Fig. 11 shows single electron pulses obtained from a VLPC using this preamplifier. The rise time is on the order of 5 ns, consistent with the 5 ns preamplifier rise time, indicating that a faster rise time may be obtainable, as the signals shown are limited by the preamplifier response.

Conclusion

Scintillating fibers and VLPC's can provide efficient tracking and excellent time resolution for minimum ionizing particles using long lengths of fibers. These promising results clearly indicate that this technique can play an important role in high energy physics experiments which are characterized by high particle multiplicity and require fast timing.

Acknowledgements

The authors would like to express their appreciation to Drs. M.Mishina and K.Kondo for providing the fibers, Drs. P.Besser and R.Bharat of Rockwell International Science Center for their support of VLPC research and development, Dr. D.Green of FNAL for helpful discussions and to C.Rivetta, also of FNAL, for valuable help with analog electronics. Finally, we would like to thank F.Chase and J.Kolonko of UCLA for essential technical support and to S.Sahlman for help with data aquisition.

References

[1] Fiber Tracking Group: B. Abbott[k], D. Adams[i], E. Anderson[j], M. Atac[a,b], C. Anway[a], A. Baumbaugh[b,d], P. Berge[b], P. Besser[j], R. Bharat[j], M. Binkley[b], J. Bishop[b], N.Biswas[d], A.D. Bross[b], C. Buchanan[a], N. Cason[d], R. Chaney[k], D. Chrisman[a], A. Clark[b], D.Cline[a], H. Cohn[e], M. Corcoran[i], R. Davis[h], J.Elias[b], E. Fenyves[k], D. Finley[b], G.W. Foster[b],J.M. Gaillard[b], J. Godfrey[d], H. Goldberg[c], H. Hammack[k], X. Huang[d], J. Jacques[d],V. Kenney[d], R. Kephart[b], D. Koltick[h], J. Kolonko[a], K. Kondo[l], R.A. Lewis[f],J. Marchant[d], R. McIlwain[k], S. Margulis[c], H. Miettenen[i], R. Moore[g], R.J. Mountain[d],T. Okusawa[f], J. Park[a], M. Petroff[f], J.Piekarz[d],A. PlaDalmau[b], R. Ruchti[d], R. Scalise[g], W. Shepard[d], E. Shibata[h], G.A. Smith[g],J. Solomon[c], K. Takikawa[l], S. Tkaczyk[b], and R. Wagner[b]

[a]University of California at Los Angeles

[b]Fermi National Accelerator Laboratory

[c]University of Illinois at Chicago

[d]University of Notre Dame

[e]Oak Ridge National Laboratory

[f]Osaka City University

[g]Pennsylvania State University

[h]Purdue University

[i]Rice University

[j]Rockwell International

[k]University of Texas at Dallas

[l]Tsukuba University

[2] M. Atac, J.Park, D.Cline and D.Chrisman, To be published NIM06841 (1992)

[3] M.D. Petroff and W.G. Stapelbroek, IEEE Trans. Nucl. Sci. N.S.36, 158 (1989) ; M.D. Petroff and M.Atac, IEEE Trans. Nucl. Sci. N.S.36 163 (1989).

[4] R.J.Yarema,T.Zimmerman,W.Willams,M.Binkley, T.Huffman,R.Wagner, IEEE 1991 Nucl. Sci. Symposium.

Figure Captions

Figure. 1

Experimental arrangement for the cosmic ray tests.

Figure. 2

Arrangement of the fiber ribbon matrix. The numbered fibers in each ribbon were used for the tests. The geometry was determined by using charged cosmic ray tracks, trigger on fibers in the first and the fourth layers and determining the hit fibers in the second and third layers.

Figure. 3

Charge calibration using a ^{60}Co source. The photoelectron peaks were produced by detecting the photons produced by Compton electrons from the 1 MeV gamma rays. The peaks clearly identify the number of multiple photoelectons detected by one of the VLPC's. This excellent pulse height resolution shows the power of the VLPC's in counting as few as one photon. We also see the pedestal noise peak.

Figure. 4

The number of photoelectrons versus the charge in picocoulombs. This was determined for all fibers in the second and third layers.

Figure. 5

Charge calibration per photoelectron for fibers 4 through 11. The variations are mainly due to the gain variations of the amplifiers. A separate test showed that the VLPC gain variations are within 5% under the same bias voltage.

Figure. 6

The photoelectron distribution obtained from the cosmic rays passing through the fibers of the third layer at the distance of 6.5 meters from the VLPC's. It shows a Landau-like distribution. This is expected from thin fiber sampling of dE/dX.

Figure. 7

The average number of photoelectrons obtained from layer 2 and layer 3 fibers at the indicated cosmic ray telescope positions with the mirror at the end of the scintillating fibers. It also shows one position without the mirror in place.

Figure. 8

Typical charged particle tracks. The number of photoelectrons detected from each fiber is indicated. The tracks are very clean. For these events, a 0.5 photoelectron threshold was used. There was no detectable cross-talk between the fibers.

Figure. 9

Two, computer selected, unusual tracks showing that an excessive number of photoelectrons may be produced within a fiber or neighboring fibers by the passage of minimum ionizing particles. Delta rays could produce these excessive photoelectrons.

Figure.10

Fiber tracking efficiency for fibers in layers 2 and 3 as a function of photoelectron threshold cut. In addition it shows the efficiency if layer 2 or layer 3 were hit. The efficiency for he half fiber staggered doublet is around 99% . For these plots the two middle fibers of layers 1 and 4 were used as triggers. The apparent efficiency at the threshold cut below 1 photoelectron, is due to some triggers being produced by electronic noise and therefore it is not a true inefficiency.

Figure.11

Single electron pulses obtained from a VLPC through a fast CDF-VTX amplifier. It shows a rise time less than 5 ns, with excellent signal to noise characteristics.

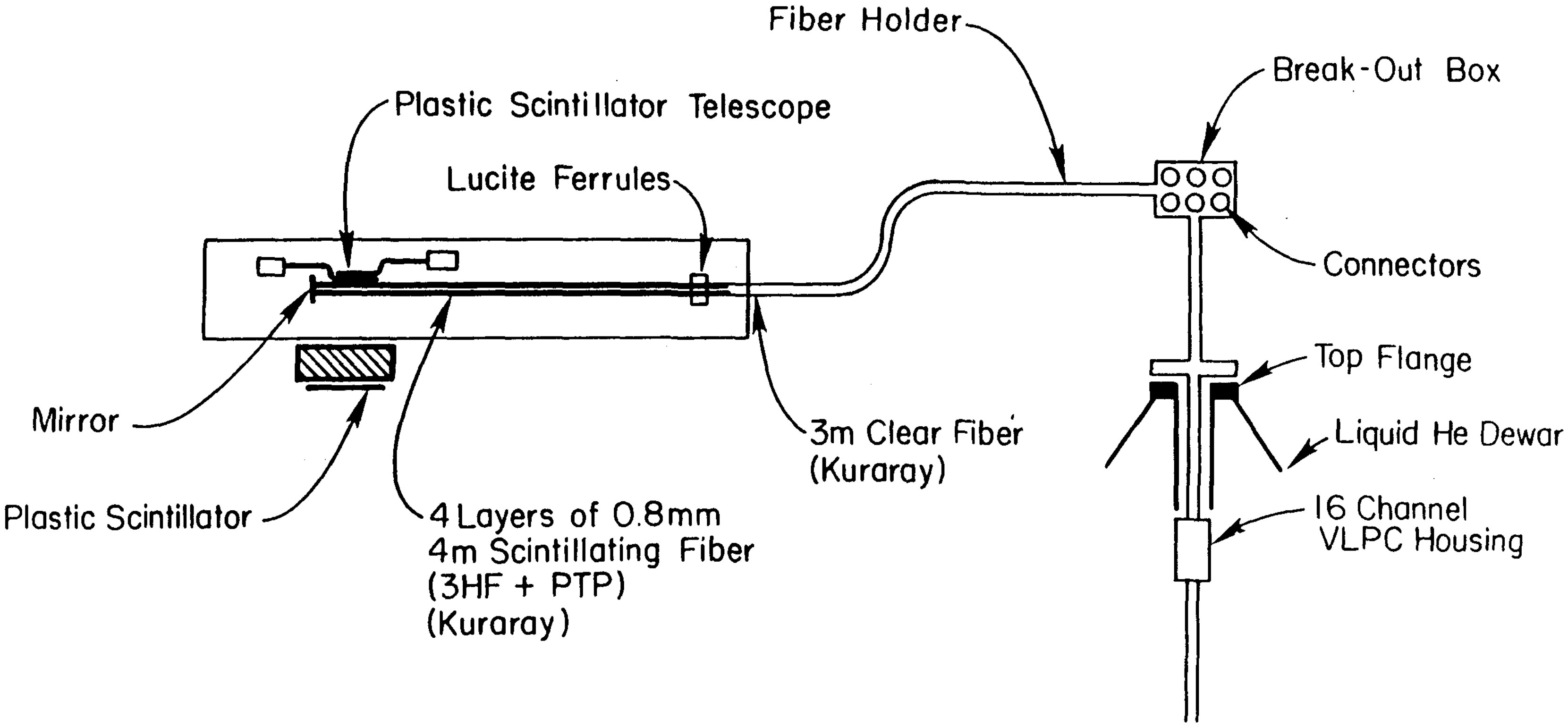

Fiber Holder
Break-Out Box
Plastic Scintillator Telescope
Lucite Ferrules
Connectors
Top Flange
Mirror
3m Clear Fiber
(Kuraray)
Liquid He Dewar
16 Channel
VLPC Housing
Plastic Scintillator
4 Layers of 0.8mm
4m Scintillating Fiber
(3HF + PTP)
(Kuraray)

Fig. 1

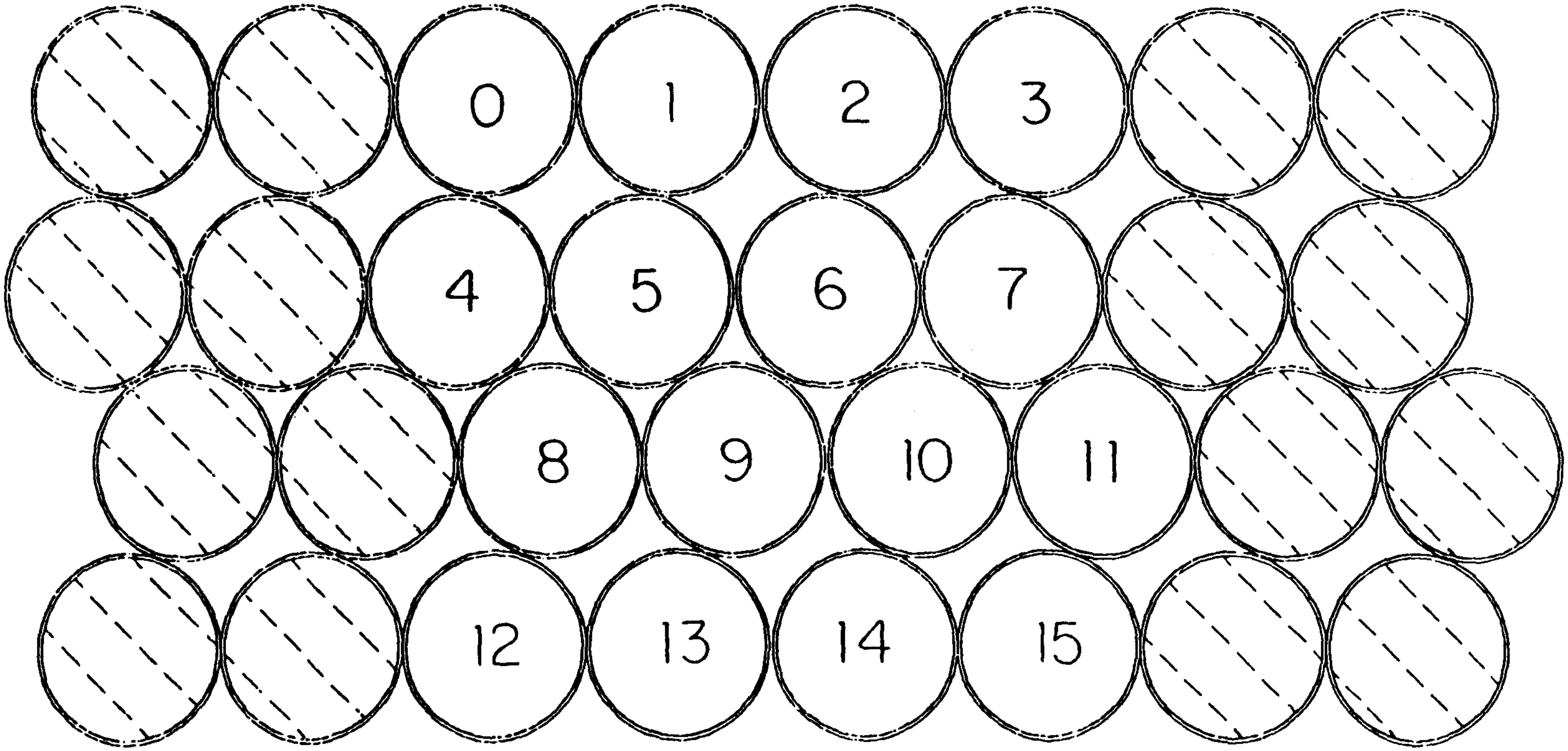


Fig. 2

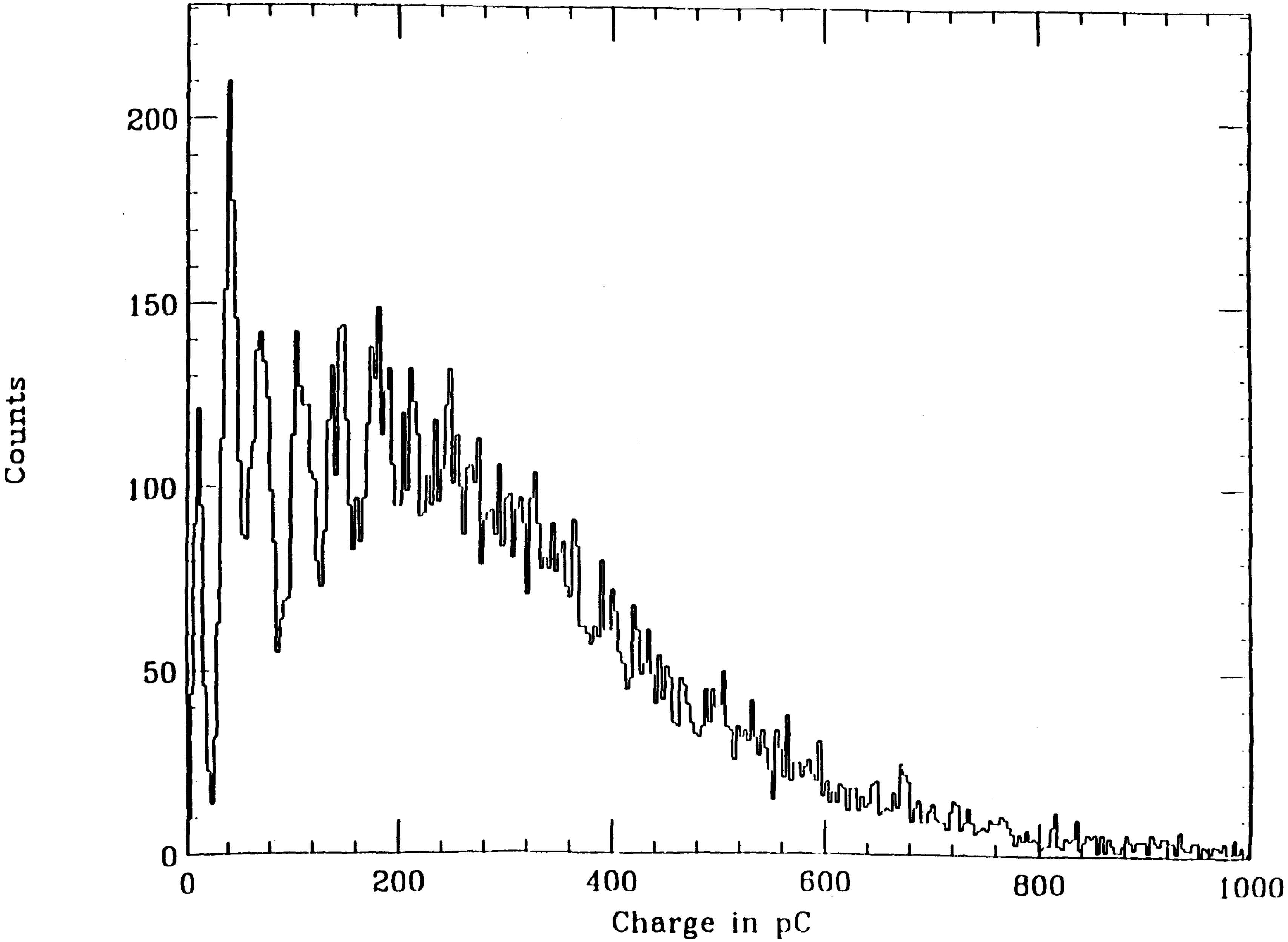


Fig. 3

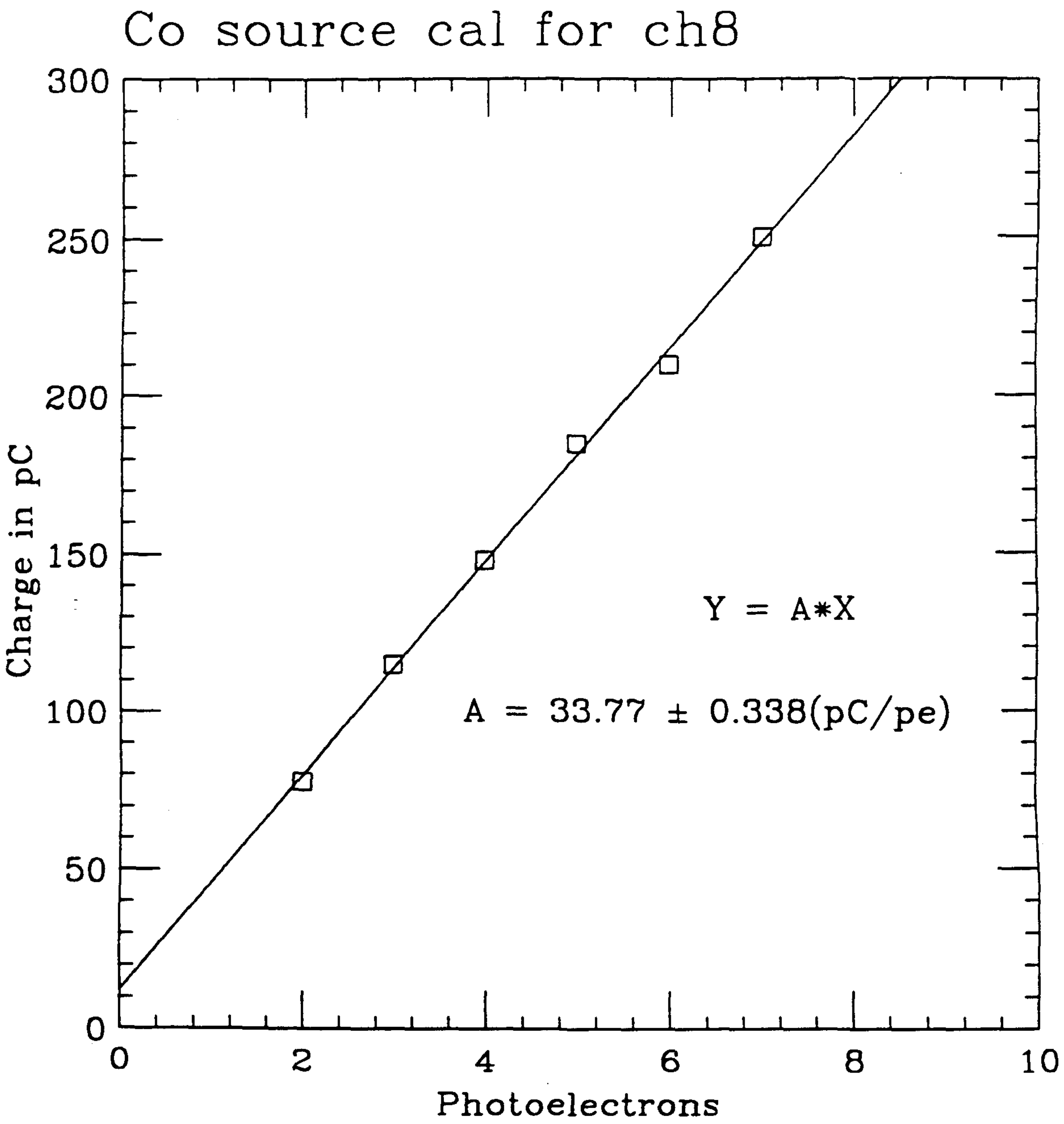

Co source cal for ch8
Charge in pC
Photoelectrons
Y = A*X
A = 33.77 ± 0.338(pC/pe)
300
250
200
150
100
50
0
0
2
4
6
8
10

Fig. 4

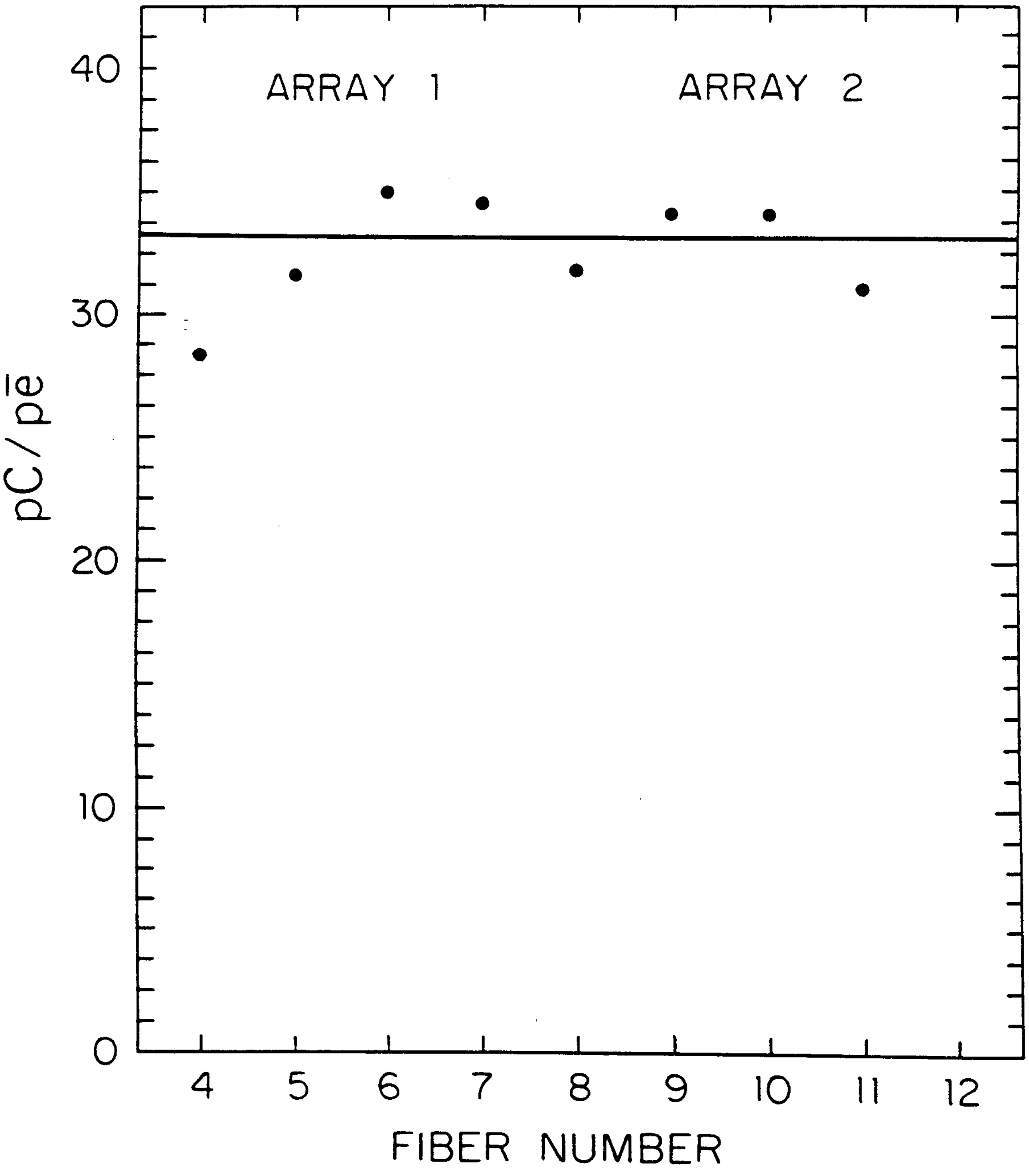


Fig.5

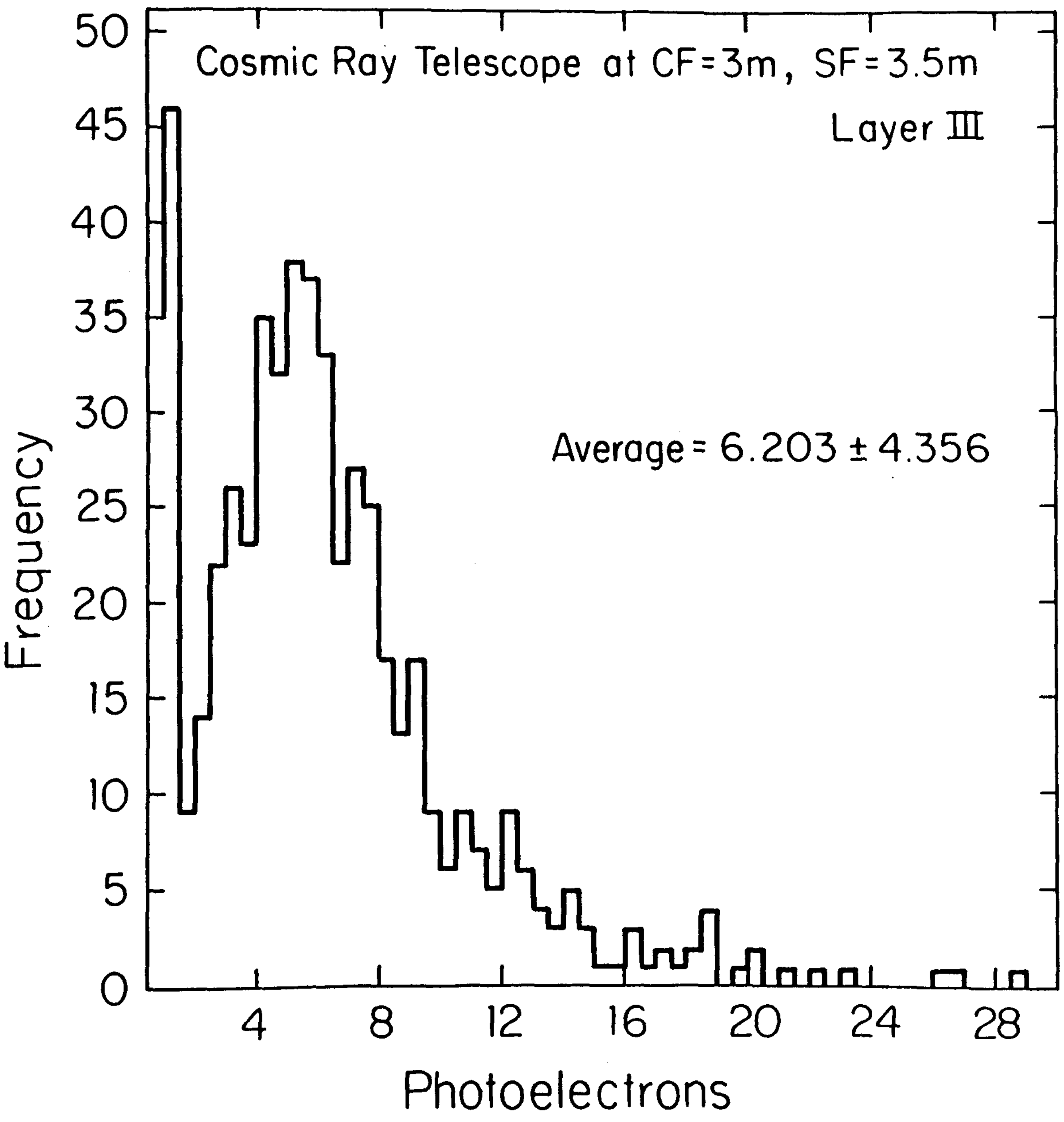

Cosmic Ray Telescope at CF=3m, SF=3.5m
Layer III
Average = 6.203 ± 4.356
Frequency
0
5
10
15
20
25
30
35
40
45
50
Photoelectrons
4
8
12
16
20
24
28

Fig. 6

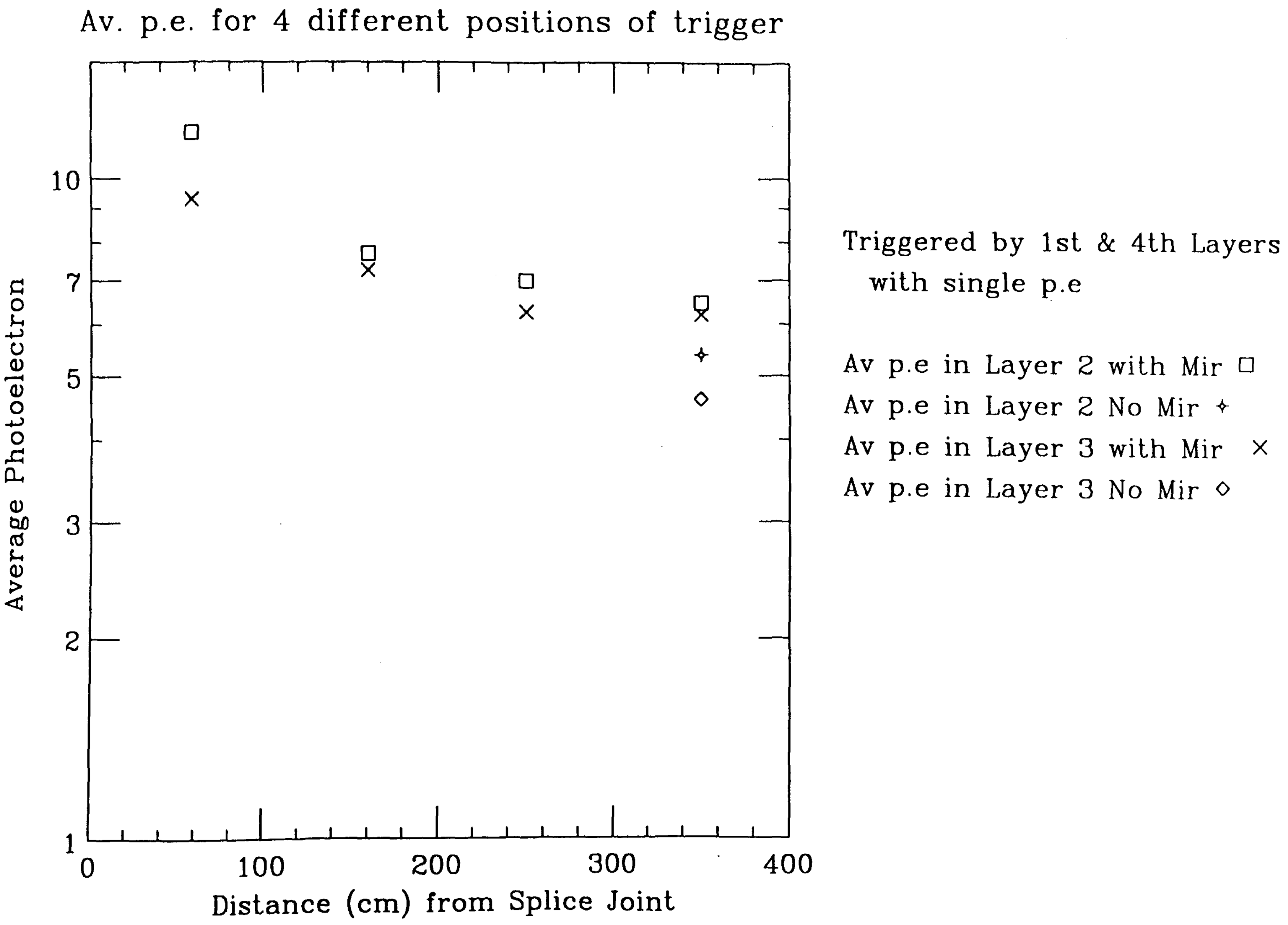

Av. p.e. for 4 different positions of trigger
Average Photoelectron
Distance (cm) from Splice Joint
1
2
3
5
7
10
0
100
200
300
400
Triggered by 1st & 4th Layers with single p.e
Av p.e in Layer 2 with Mir □
Av p.e in Layer 2 No Mir ✧
Av p.e in Layer 3 with Mir ×
Av p.e in Layer 3 No Mir ◇

Fig. 7

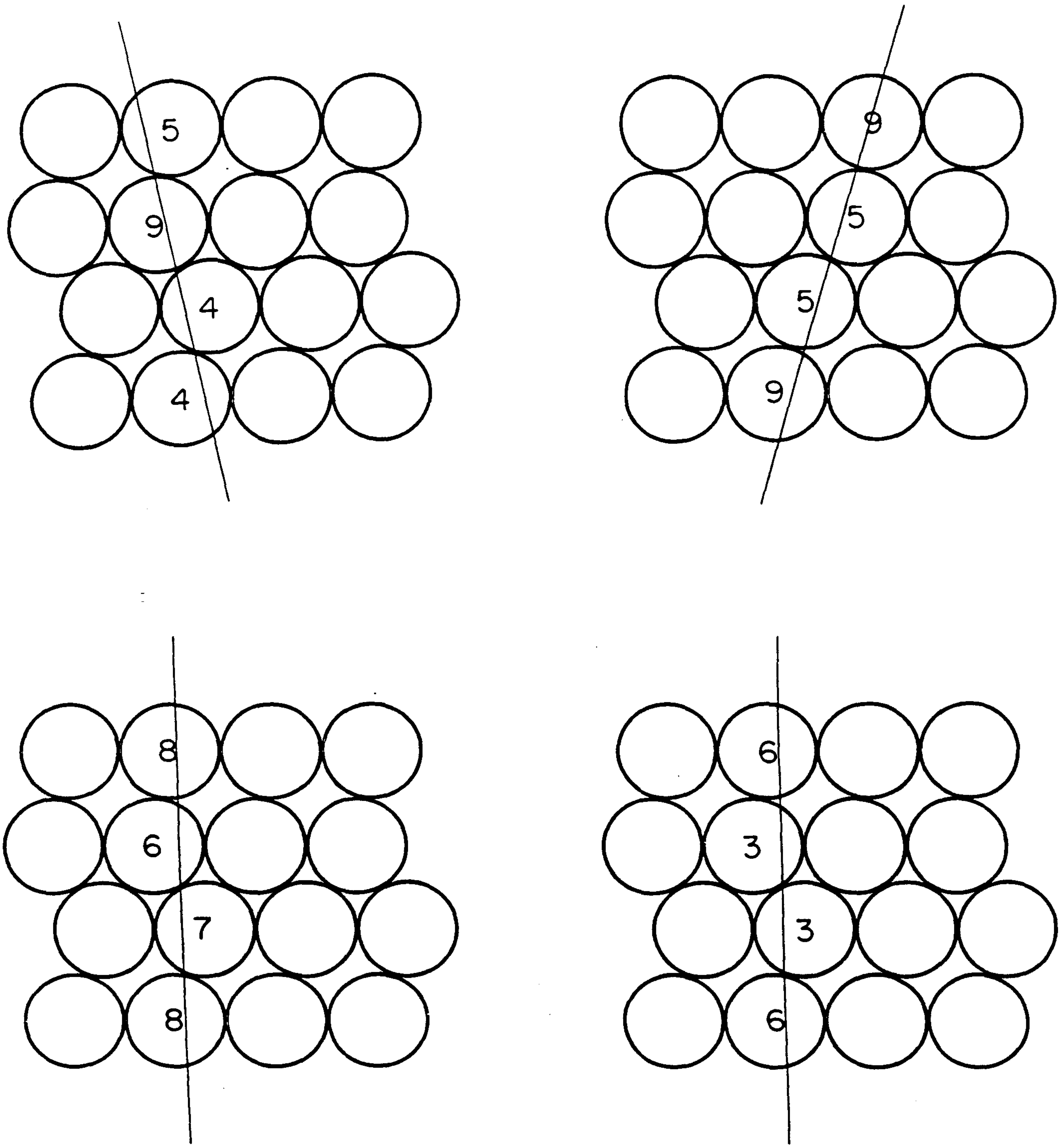


Fig. 8

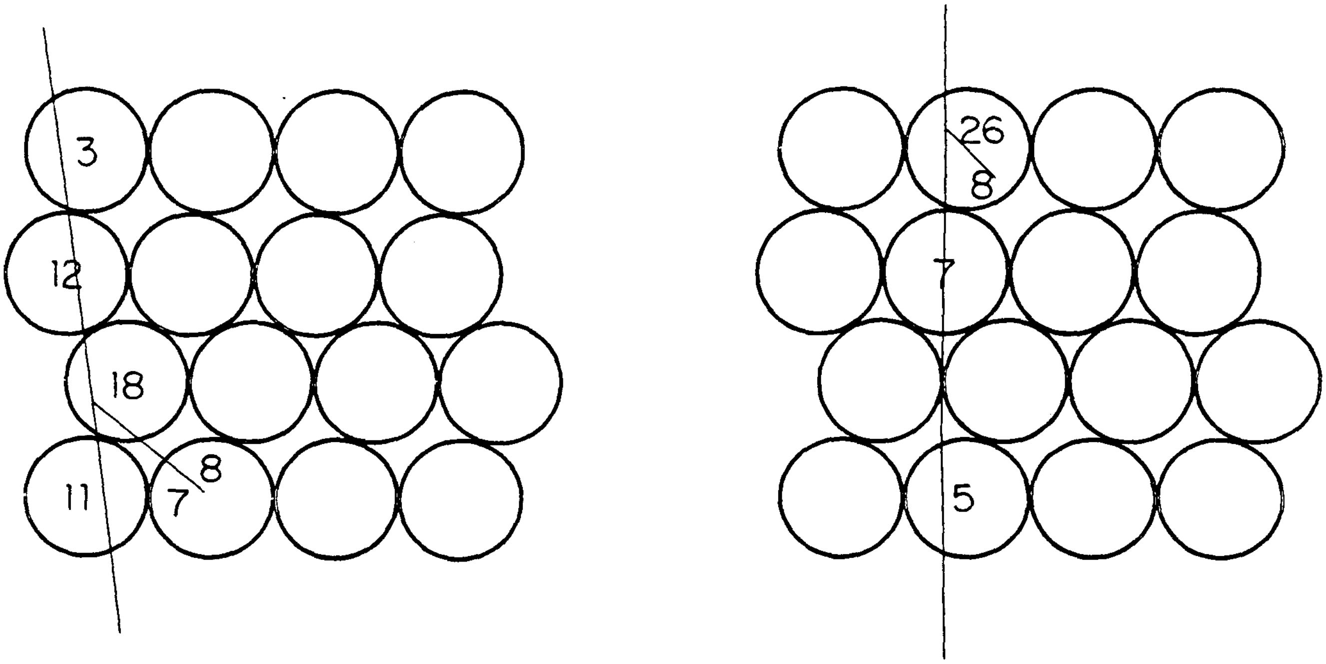
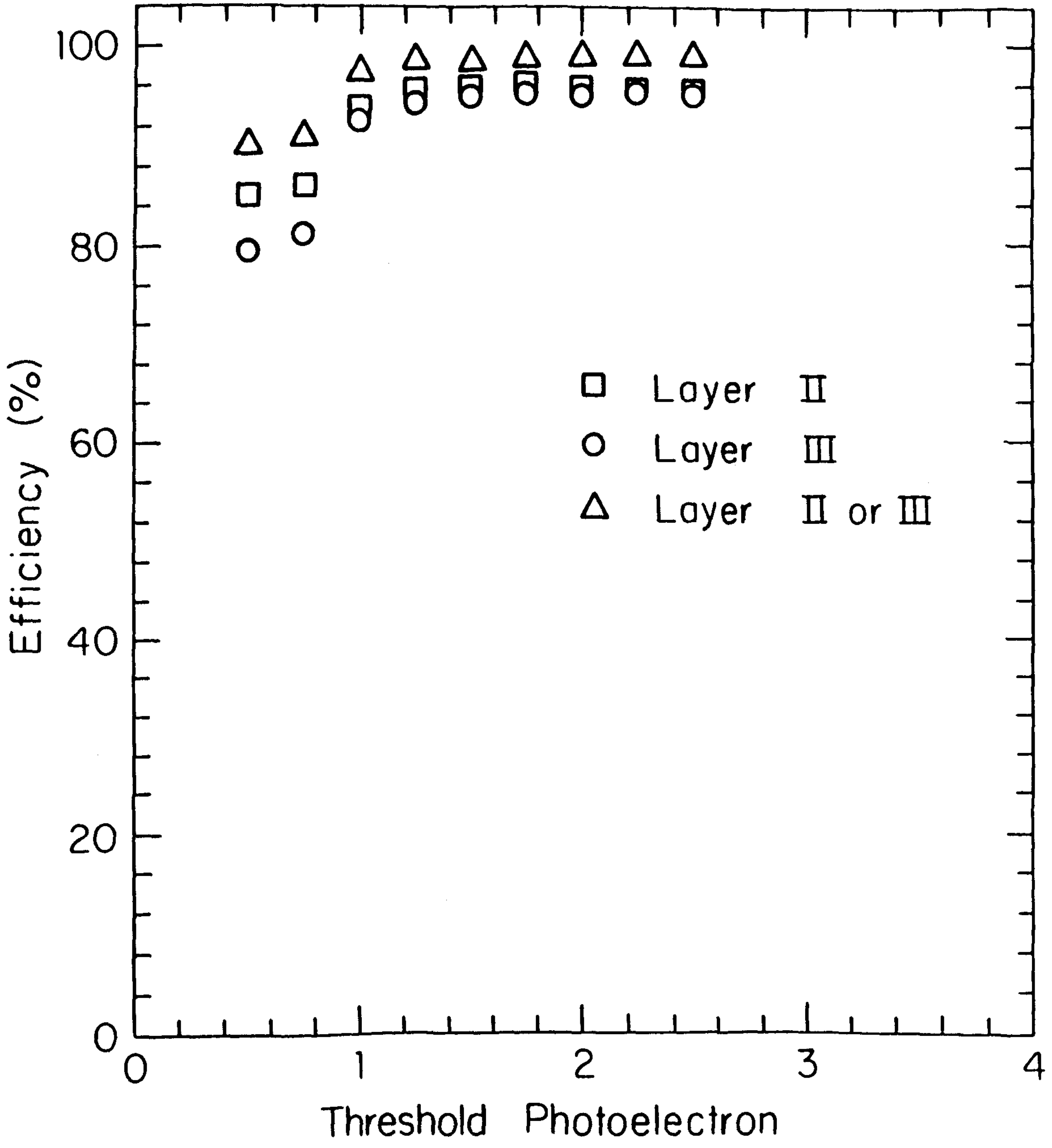


Fig. 9



100
80
60
40
20
0
0
1
2
3
4
Efficiency (%)
Threshold Photoelectron
□ Layer II
○ Layer III
△ Layer II or III

Fig. 10

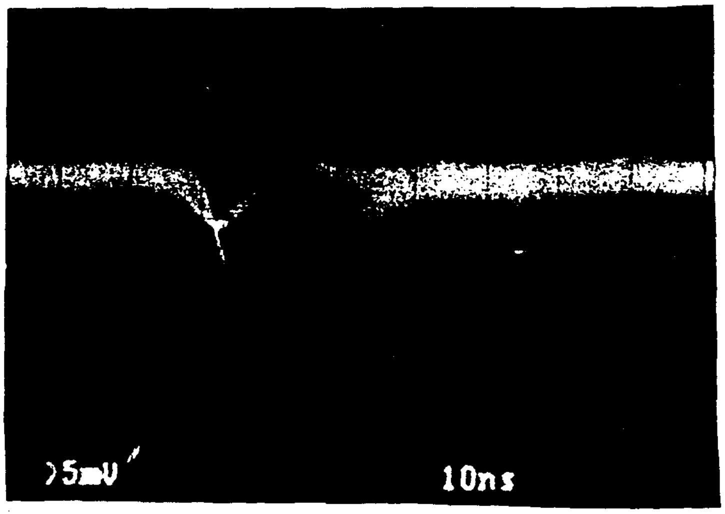


Fig. 11